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PROJECT EGRESS: THE DESIGN OF AN ASSURED CREW RETURN VEHICLE FOR THE SPACE STATION

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Keeping preliminary studies by NASA and industry in mind, including the official Request for Proposal (RFP) published by NASA Johnson Space Center, a conceptual design of an Assured Crew Return Vehicle (ACRV) has been developed. The system allows the escape of one or more crewmembers from Space Station *Freedom* in case of emergency. The design of the vehicle addresses propulsion, orbital operations, reentry, landing and recovery, power and communication, and life support. In light of recent modifications in Space Station design, Project EGRESS (Earthbound Guaranteed ReEntry from Space Station) pays particular attention to its impact on Space Station operations, interfaces and docking facilities, and maintenance needs. A water-landing, medium-lift vehicle was found to best satisfy project goals of simplicity and cost efficiency without sacrificing the safety and reliability requirements of the RFP. With a single vehicle, one seriously injured crewmember could be returned to an Earth-based health facility with minimal pilot involvement. Since the craft is capable of returning up to five crewmembers, two such permanently docked vehicles would allow a full evacuation of the Space Station. The craft could be constructed entirely with available 1990 technology, and launched aboard a shuttle orbiter.

INTRODUCTION

NASA has a longstanding dedication to the concept of Assured Crew Return Capability (ACRC). The first trajectories of the Mercury and Gemini programs assured the return of the capsule into the atmosphere. The dedication to ACRC continued during the Apollo missions, which flew in a "free return" trajectory. This trajectory allowed the capsule to circle the Moon and return to Earth automatically in the event of an emergency. Furthermore, the Lunar Module had the capacity to serve as an emergency vehicle. On November 13, 1970, the explosion of an oxygen tank aboard the Apollo 13 Service Module mortally damaged the tanks and systems inside the vehicle, and forced the crew to use the Lunar Module for the return to Earth.

NASA continued to assure the return of any space-based crew during the Skylab missions. Crew return was assured by the Apollo capsule, which transported the crew to Skylab and remained docked at the orbiting lab throughout the mission. In addition, NASA configured an Apollo capsule to carry five crewmembers (the normal capacity of an Apollo capsule was three crewmembers) so that two crewmembers could travel to Skylab and return to Earth with the Skylab crew.

However, unlike the Apollo capsule on Skylab, the crew transportation vehicle for Space Station *Freedom* (the space shuttle) will not remain docked at the station during the crew work cycle (approximately 90 days). NASA originally planned for the space shuttle to assure the return of *Freedom's* crew. However, the tragic explosion of the Space Shuttle *Challenger* over the Atlantic Ocean on January 28, 1986, forced NASA to reevaluate the means of assuring the return of any or all of *Freedom's* crew. In order to assure the safe return to Earth of the Space Station crew, NASA proposed and issued a Request For Proposal (RFP) for an Assured Crew Return Vehicle (ACRV).

MISSION OVERVIEW

The ACRV will serve as an alternative return vehicle from the Space Station. The ACRV will be permanently docked at Space Station *Freedom* and will serve *Freedom* in three primary design reference missions: (1) The return of the entire Space Station crew (eight crewmembers) in the event that the space shuttle is unavailable; (2) the return of the entire Space Station crew in the event rapid evacuation from Space Station *Freedom* is required; and (3) the return of an injured or ill crewmember in the event that rapid return is required.

The goal of the EGRESS team was to design a vehicle that would be simple, reliable, and would minimize impact on existing programs. Simplicity and reliability are always goals in the design of a space vehicle, but even more so for an emergency vehicle. In order to reduce impact on existing programs the design of the vehicle would need to minimize both crew training and maintenance requirements and maximize independence from the Space Station.

Keeping in mind the old adage "what goes up must come down," the EGRESS design team needed to determine how the vehicle would return to Earth. The primary concerns were the lift-to-drag ratio (L/D) and the vehicle's landing mode. Initially, a high lift-to-drag, such as the shuttle or an aeroplane, was researched by the team. A high lift-to-drag vehicle encounters low forces during reentry and is very maneuverable; however, it would require wings to generate lift. The RFP requires that the ACRV fit into the space shuttle cargo bay, which has a diameter of 15 ft. This stipulation would require a winged ACRV to have retractable wings, which are both mechanically and structurally complicated. In addition, such a vehicle configuration would require complicated control surfaces to control yaw, pitch, and roll maneuvers. Finally, a high L/D would require extensive initial training and continuous refresher training for pilots of the vehicle. On the other hand, a low L/D vehicle is simpler to operate and requires less training time. Since the Mercury, Gemini, and Apollo vehicles were all low L/D vehicles, a low L/D vehicle uses flight-proven hardware. However, low L/D vehicles encounter high reentry forces and have limited, if any, maneuverability. Thus, the design team chose a medium L/D for the EGRESS vehicle. This configuration will encounter mild reentry forces and have modest maneuverability, while still being simple to operate.

After the decision to design a medium L/D vehicle was made, the team needed to determine the landing mode of the EGRESS vehicle. The two possible places for a vehicle to land are on land or in the water. A land landing vehicle would allow for landing site selection in close proximity to a health care facility allowing rapid transportation of an injured or ill crewmember to the facility. In addition, a land landing vehicle would be reusable since it would not suffer the corrosive effects of salt water. However, since the vehicle was to have a medium L/D it would not be capable of gliding to a landing site as the space shuttle does. Instead, the vehicle would need to deploy parachutes to slow its descent, and then use an impact system (such as retro rockets or airbags) to minimize its impact with the ground. This configuration would still encounter large impact loads at touchdown. Since the EGRESS vehicle must have the capability to return an injured or ill crewmember, it is desirable to minimize the impact loads experienced by the occupants of the vehicle. Furthermore, a land landing vehicle would require extensive training in order to complete the precise maneuvers required for an accurate landing.

The impact loads encountered during a water landing are less than those of a land landing, which makes the water landing more desirable for the return of an injured or ill crewmember. Furthermore, a water landing does not require the accuracy of a land landing, and will not require the extensive training for landing procedures. Thus the EGRESS team chose to design a medium lift-to-drag vehicle that will land in the water.

The specific locations of the landing sites were determined from the availability of recovery forces and health care facilities, and the groundtrack. The limiting factor in the recovery forces proved to be the availability of a heavy lift helicopter capable of lifting 10,000 lb, the weight of EGRESS. In addition to the weight constraints of the recovery forces, the groundtrack imposed further constraints on the landing site selection process. Only a small portion of the groundtrack goes over the United States or coastal areas with nearby U.S. military bases. The second Design Reference Mission requires the craft to leave with relatively short notice; therefore it is desirable to have the craft land at a primary landing site from any of its orbits. With these criteria in mind, Pearl Harbor (Hawaii), Okinawa (Japan), and Kennedy Space Center (Florida) were chosen as the primary landing sites, and Guam was chosen as a secondary site. The health care facilities available at the landing sites are Pearl Harbor Naval Hospital, Kadena Naval Hospital, Patrick Air Force Hospital, and Anderson Air Force Hospital, respectively. Two vehicles will be stationed at *Freedom*, while four vehicles will be on the ground to provide both support and redundancy. In addition to replacing used vehicles, the ground-based vehicles will allow the spacecraft to be updated. The two vehicles aboard the Space Station will be placed at nodes 1 and 2 of the Space Station, resulting in ease of departure from the station and minimum interference to the Space Station operations.

The remainder of this report discusses the structure of the EGRESS vehicle, the internal configuration, mission analysis, and training requirements.

VEHICLE STRUCTURE

The design of the vehicle structure consisted in consolidating the varied requirements of a space vehicle. After the design process leading to the final configuration is presented, the two additional components of Project EGRESS are described.

Design Process

To adhere to the design goals of simplicity and reliability, a vehicle based closely upon the Apollo reentry capsule was envisioned. However, the Apollo provided only a low L/D. The EGRESS vehicle needed to feature medium-lift capabilities. This was accomplished with the use of a bent-nose biconic reentry vehicle. The Apollo module was a conic vehicle. A biconic would be formed if the nose cone of the Apollo were stretched into a longer cone, with the rest of the vehicle unchanged, and then bent at an angle to the rest of the vehicle. EGRESS was designed to be a medium-lift vehicle thus capable of a cross-range travel much greater than that of an Apollo vehicle. In addition, EGRESS will have better thermal emissivity characteristics and lower reentry accelerations than Apollo.

To achieve the desired aerodynamic characteristics, the vehicle required certain shape constraints and a minimum wetted surface area. One of the shape constraints imposed by atmospheric reentry was that the vehicle's hatch be protected from reentry burn-up by placing it behind the vehicle's nose from an angle of impingement of 60°. The shape of the vehicle was designed to meet all these requirements, as well as to fulfill the mission guidelines. EGRESS was first transformed into a flattened bent biconic and then slowly transformed into what was referred to as a "raft" shaped vehicle.

The final configuration developed from an amalgamation of existing and experimental reentry vehicles. The EGRESS vehicle is squat with a rounded, triangular body that is 13.5 ft long, 6 ft high, and 9 ft wide, that weighs 8018.83 lb, and that has an exterior volume of 355 cu ft and an interior volume of 250 cu ft. In addition to the reentry vehicle, the EGRESS system has a deorbit propulsion package that is detachable from the vehicle. These components are shown in Fig. 1. An airlock was also designed.

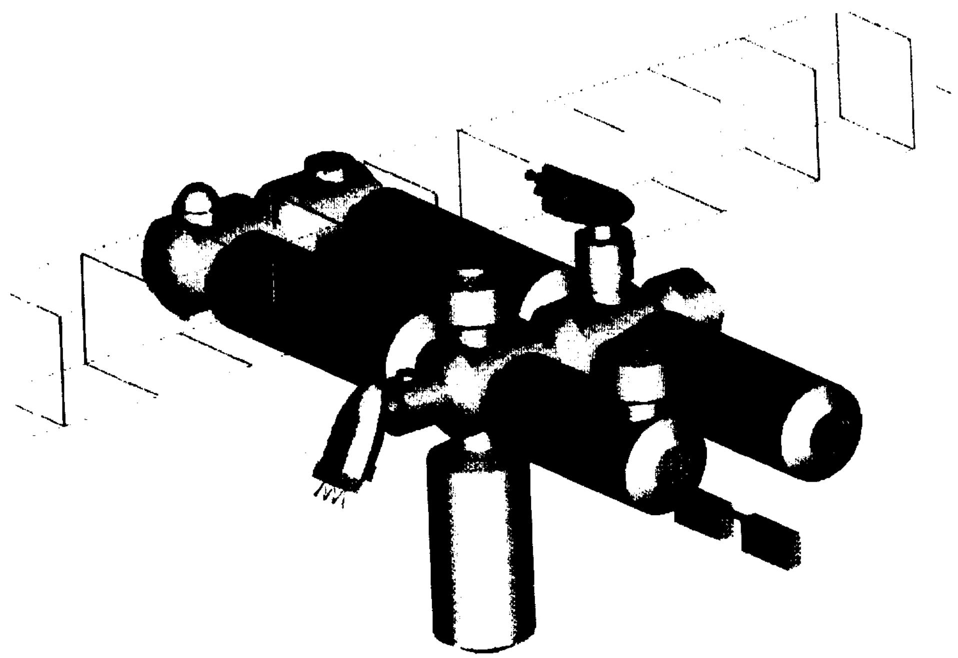

Fig. 1. Components of Project EGRESS

Airlock

During normal Space Station operations, astronauts will be conducting regular Extra Vehicular Activity (EVA) missions in pairs. The EVA astronauts can enter the Space Station through designated EVA airlocks at only a few nodes. If a Space Station catastrophic failure terminates either the Space Station power system or any nodes between the astronauts' entrance airlock and the EGRESS, the EVA astronauts will not be able to enter the EGRESS. In order to assure that EVA astronauts will be able to enter the EGRESS during a station integrity failure, EGRESS must have its own airlock.

The airlock is a short cylinder with length 6.25 ft and diameter of 8 ft, an inner volume of 332 cu ft, a total mass of 3282 lb, and the ability to contain and to sustain two spacesuited astronauts. The airlock is double-hulled to protect it from meteoroid impact that would cause habitable airlock lifetime to diminish.

Propulsion Package

EGRESS's engines, fuel, and pumping systems will be contained in a jettisonable structure separate from the main body of EGRESS, as shown in Fig. 1. This structure will be jettisoned following the deorbit burn for two reasons. First, dumping the propulsion pack will decrease both the mass and the drag of the vehicle. Second, placing the propulsion pack in a safe orbit will allow the pack to be reused. EGRESS will perform a small separation maneuver after which the structure will use some of the remaining fuel to put itself in a safe orbit where it will be retrieved later.

The propulsion package consists of three rocket engines and a box framework. EGRESS will use three R-40 engines in a straight line to accomplish the deorbit burn. With this arrangement a normal burn would be performed with all three engines. In the event that the center engine fails, the two outside engines would be ignited. In the event that one of the end engines fails, two options exist: burning only the center engine or burning the center and remaining engine while compensating for induced moments by RCS jets. The framework houses two sets of fuel and two sets of oxidizer in four spherical tanks, two sets of helium propellant-feed also in spherical tanks, and four reaction control system thruster clusters. The box framework is 7.8 ft tall, 7.4 ft wide, 3.4 ft thick, and weighs 108 lb. The total weight of the propulsion package is 2275 lb.

INTERNAL CONFIGURATION

Since the EGRESS vehicle must transport humans, the internal configuration of the craft is as important as the external structure. Internal configuration consists of design and layout of the crew cabin, determination of crew size, and design of life support systems.

Crew Cabin Design

Each EGRESS vehicle will be configured to return up to five crew members. The crew size is based upon both the basic configuration requirements and the duties of the different crewmembers. The primary crew of a pilot, a patient, and a medical technician will be seated in the rear "top row" while the secondary crewmembers will sit in the jump seats in the "bottom row" of the cabin. These configurations will allow easy access to necessary controls and provisions, easy entry and exit of the vehicle, and maximum center of gravity stabilization during the flight. The crew configuration in the EGRESS vehicle is shown in Fig. 1.

Pockets on the sides of the cabin will carry pressurized pens, clipboards, notepaper, and "cue cards" outlining flight and medical procedures for use during an EGRESS flight. Food will also be stored in these pockets. Flashlights and penlights will be provided for use during systems checkouts, EGRESS flights, and recovery. Waste management equipment and supplies are stored under the medical technician's seat on the floor of the crew cabin. The majority of the critical care medical equipment, including one package of ventilator tubing, two liters of lactated Ringers solution, and intravenous lines, will be stored in a medical supply kit on the floor of the crew cabin when not needed. "Trauma pants" with inflatable leg chambers, also stored in this kit, will allow a patient to better withstand the *g* forces of reentry. General-use medical supplies, including bandages, alcohol prep-pads, needles, and syringes, are located in pockets on the wall of the crew cabin next to the medical technician. Two fire extinguishers, one located within reach of the pilot and another in the rear of the craft, will give the crewmembers the ability to quickly control and put out fires in the crew cabin. An emergency supply kit will carry five automatically inflatable life jackets, a flare gun with flares, and other provisions needed to ensure the safety and survival of the crew during a wait for recovery. In addition, an automatically inflatable five-person raft, stored behind the jump seats at the front of the crew cabin, will allow the crew safe exit from the EGRESS vehicle if required.

Crew Size

EGRESS is capable of returning three to five crewmembers from the Space Station. For the return of an injured or ill crewmember, at least two crewmembers are needed to support the injured crewmember as stated previously. After such a mission, five crewmembers would be left aboard ***Freedom*** to continue normal operations; thus a second EGRESS vehicle must be capable of returning the remaining five crewmembers to avoid the need for a third vehicle. All crewmembers must be evacuated from the station on the two EGRESS vehicles attached to the Space Station. Assuming a Space Station crew of eight, three crewmembers will ride in one vehicle and five in the other. The EGRESS spacecraft carrying three crew members will be used to transport critical experiments and equipment back to Earth, if necessary.

Life Support Systems

Absolutely essential to the successful utilization of the EGRESS spacecraft is the presence of a simple but efficient Environmental Control and Life Support System (ECLSS) on the vehicle. The EGRESS ECLSS is composed of two main systems: an environmental and atmospheric control system, and a life support system. Other supporting systems included a waste management system and a crew water and food provisioning system.

The Atmospheric Supply and Pressurization System will provide a cabin pressure of 14.7 psi and a 21% oxygen, 79% nitrogen atmosphere in order to provide a safe, comfortable environment for the crew during a normal flight of the EGRESS vehicle. In addition, the system contains redundancy and emergency features to allow environmental support in emergency situations. Constant monitoring of the total cabin pressure and oxygen partial pressure will be done by the Main Environmental Control System. In addition, EGRESS will provides a patient a higher oxygen concentration through a Patient Environmental Control System, a separate environmental loop that processes exhaled air for up to 48 hr.

The life support system will meet all the physiological requirements of up to five crewmembers for 24 hr. Medical systems will allow advanced life support for one ill or injured crew member on board the EGRESS for up to 48 hr. The interior systems, including the seats, control panels, windows, and general provisions, were all designed and placed within the EGRESS crew cabin according to the basic physiological, ergonomic, and psychological requirements of five crewmembers.

Because space travel and reentry into the atmosphere inherently involve risks to human life, criteria for use were developed to ensure that the EGRESS vehicle will only be used when remaining on the Space Station would pose greater risks than would returning to Earth. These criteria were also used as a basis for defining the necessary crew systems and provisions according to the use of the vehicle.

MISSION ANALYSIS

If the EGRESS vehicle were to be used, its mission would follow an established sequence of events. The mission would consist of startup, orbital maneuvers, atmospheric reentry, and landing and recovery. After the recovery and processing of the vehicle, a new vehicle will be launched into orbit. Like the original two vehicles aboard the Space Station, any new vehicles will enter the established maintenance cycles.

Startup

EGRESS is powered by primary, nonrechargeable batteries during its operations. Power will also be provided to EGRESS from Space Station *Freedom* using a rechargeable nickel-hydrogen battery system as a reservoir. Power will be distributed to EGRESS systems using four main buses. Two major interface areas are present in the power distribution system, one between EGRESS and the propulsion module, and the other between EGRESS and the Space Station. Power will be distributed and monitored using state-of-the-art software in order to help detect problems before they develop, and isolate problems that may surface.

The communication system is primarily based on S-band radio transmissions. This system will use the Tracking and Data Relay Satellite System (TDRSS), which is currently used by the space shuttle, to relay signals to the ground. EGRESS will also use a Very-High Frequency (VHF) system to communicate with search and rescue forces. The VHF system could serve as a backup for voice communications if there are problems with the primary S-band system. L-band communications will also be used to receive signals from the Global Positioning System satellites in order to accommodate the navigation system described below.

The EGRESS computer system, which is in control of most of the EGRESS subsystems throughout a crew return mission, is designed for reliability. The processing units, high-powered space-rated IBM AP101S general purpose computers, are linked in a triple redundant configuration. The computers are connected to an optical disk mass storage device and the rest of the vehicle's subsystems, through a 24-bit data bus. Under control of the EGRESS Automated Software Environment, the system is responsible for regulating the power and life support systems, as well as serving as the flight management system and controlling most of the vehicle's operations.

In order for the EGRESS vehicle to accomplish its various missions, it is important that the vehicle have accurate navigation and guidance for control. The navigation system consists of an inertial navigation system (INS) that is augmented by the Global Positioning System (GPS). The Honeywell CG1320 INS, based on a ring laser gyroscope, is used to provide highly accurate attitude information. By incorporating GPS into the system, a precise position can be determined to within 15 m. Though the system is normally initialized while the EGRESS vehicle is docked, initialization can take place after separation in the rapid evacuation scenario.

Orbital Maneuvers

The EGRESS vehicle's mission will begin with separation from the Space Station. This separation will consist of two phases. The first phase is a 1 ft/sec positive radial burn that will last approximately three minutes. EGRESS will use a gaseous nitrogen system to separate from the station. Two clusters of two 1-lbf cold gas thrusters will be placed on either side of the vehicle to allow separation at 1 ft/sec from either node 1 or node 2.

When EGRESS reaches a height of 150 ft above the station, the second phase of separation will begin. This maneuver will consist of a 2 ft/sec retrograde burn that will put the EGRESS in proper position for the deorbit burn after approximately 40 min. For on-orbit maneuvers, EGRESS will be equipped with 42 reaction control jets. There will be one cluster of 16 across the nose of the vehicle and two clusters of 11 each in the aft section of EGRESS.

The deorbit burn will be a retrograde burn, and the transfer will resemble a Hohmann transfer. The retrograde motion will allow the EGRESS vehicle to transfer from the station's orbit to the 400,000-ft atmospheric boundary. The time and velocity change required for the maneuver depends on the station's altitude. At the minimum altitude of 140 n.m., the required ΔV is 227 ft/sec, and the maneuver will take 24.4 min. At the maximum altitude of 270 n.m., the required ΔV is 391 ft/sec, and the maneuver will take 36.6 min. EGRESS will use three Marquardt R-40 engines to deorbit. The R-40 is a liquid bipropellant engine using monomethyl hydrazine as the fuel and nitrogen tetroxide (N_2H_4) as the oxidizer. The vehicle will have three engines, but will be capable of deorbiting using only one, as stated previously.

In order to insure proper fuel flow to the engines, a rubber bladder pressurization system will be used. This system employs rubber "bags" inside spherical tanks in order to separate the fuel (or oxidizer) from the pressurizing gas. This design will allow up to 99% fuel expulsion from the tanks in a zero-*g* environment.

Reentry

The EGRESS vehicle must be protected from the intense heat generated as the vehicle's kinetic energy is imparted to the atmosphere. The primary concerns were the rate of heat transfer to the vehicle and the maximum temperature experienced during reentry. A ceramic thermal protection system will be employed by EGRESS. The TPS of the EGRESS will consist of HRSI tiles covering the underbelly and nose area of the craft with an AFRSI blanket covering the remaining areas. This type of ceramic TPS is lightweight, has a high-temperature capability, will not degrade in orbit, and would be reusable if not damaged on impact with the ocean.

Additional concerns include calculation of the aerodynamic flow field about the EGRESS vehicle and the aerodynamic forces exerted by that field on the vehicle. A computer program to calculate Newtonian flow was written to provide this information. As a result of computer analysis, the EGRESS vehicle was shown to be statically stable, have a L/D of 0.7, and reenter the atmosphere at 40° angle of attack.

The attitude control system of the vehicle guides the EGRESS to its landing location. Attitude control is provided by two 65-lbf thrusters. The effects of attitude control were analyzed by another computer program that integrated the flight trajectory of the EGRESS vehicle. This trajectory analysis shows that the vehicle is capable of a cross-range of 500 n.m., which guarantees the ability of the vehicle to land at any primary landing site on either of two successive orbital passes. Furthermore, a simple flight algorithm was created that kept the *g* loads throughout reentry below 4 *g*, the *g*-loading limits of the RFP.

Landing and Recovery

The EGRESS vehicle uses a conventional deceleration system of two drogue parachutes and three flat circular parachutes that are deployed by means of three smaller pilot parachutes. An attenuation system that would provide increased deceleration right before impact is not needed since the conventional parachutes will slow the craft to an impact deceleration within the specifications of the RFP, which allows a maximum impact loading of no more than 10 *g* through the chest of an injured crewmember.

When the EGRESS splashes down, a self-righting system will automatically deploy to right the vehicle. The uprighting system will use air bags to change the center of buoyancy, causing the craft to right itself. A manual backup switch is available in the event that the automatic system fails. The self-righting system will provide additional dynamic stability to the EGRESS in heavy seas beyond the static stability of EGRESS. The center of buoyancy of the vehicle was positioned to provide a natural stability to the EGRESS vehicle allowing it to sit "nose up" in the water after landing.

Design Reference Mission 3, return of an injured crew-member, requires the crew to be removed and rapidly transported to a health care facility (HCF). For this reason, the Coast Guard was selected to remove the crew using either the HH-65A (Dolphin) or the Huey (Bell UH-1H). The Navy was selected to recover the EGRESS craft using the CH-53E (Super Stallion). The Navy would also retrieve the crew if the Coast Guard is unavailable. The EGRESS vehicle will be able to land at night with minimal changes to daylight procedure, while extremely poor weather would force a landing at another site. In the event that the only available landing sites have poor weather, a modified recovery procedure would be used in which the entire EGRESS would be lifted out of the water and transported to a HCF, with the crew inside. This procedure would avoid the possibility of the craft being swamped once the hatch is opened.

Post-Recovery Processing

Ground operations are needed to support the craft while on-orbit. Areas of ground operations include storage of replacement vehicles, mission control, and post-recovery operations. Since there will be four on-ground spares for the EGRESS vehicle, an EGRESS operations center is recommended to house the ground fleet as well as any spare parts and official documentation pertaining to the EGRESS project.

Ground control for an EGRESS mission will be handled from the mission control center for the Space Station. All EGRESS mission control personnel positions will be filled from either normal Space Station ground operations staff or any backup personnel stationed at ground control. In the event an EGRESS vehicle is used and a replacement needs to be sent in its place, the issue of replacing the ground spare was also considered. Research showed that the most cost effective alternative for replacement for the ground spare would be the construction of a new EGRESS vehicle that would reuse any properly functioning subsystems from the used vehicle. Although most of the EGRESS spacecraft will not be salvageable, certain systems inside the vehicle could be reused. However, since the craft will sit low in the water, water may spill into the cabin compartment damaging many of the systems inside the cabin area. To minimize water entry the hatch can remain closed until the crew must exit the vehicle. Attitude thrusters and separation burners will not be reusable due to salt water contamination. The displays and readouts may be damaged by salt water contamination; however, the main computers, which contain the navigation, flight operations, communications and ECLSS, will be sealed from the pressurized interior of the vehicle and will thus be protected from water damage. The parachutes used in the landing will be reusable with only minimal cleaning required. Testing and verification will need to be performed on all reusable systems to insure no damage was sustained during landing. If the systems check out then they will be used in the construction of a new EGRESS vehicle.

Launching System

The primary launch system for the EGRESS craft was specified by the RFP to be the Space Transportation System. This requirement placed certain constraints on dimensions and possible exterior configurations for placement in the payload bay. If the space shuttle were unavailable, a backup system in the form of an expendable booster was also considered. The Martin-Marietta Titan III was the most cost effective alternative and met all the necessary specifications.

The spacecraft will be attached in the space shuttle payload bay by means of a frame. This frame will attach to the payload bay by means of a longeron and keel attachments using a seven-point attachment scheme due to the weight of EGRESS. The attachment points will be connected to hard points on EGRESS's frame accessible by indented handholds so that EGRESS may be freely removed from the bay with the space shuttle's or with the Space Station's Remote Manipulator System (RMS). The frame will be made from aluminum with a diameter of approximately 2 in. The keel and longeron trunions will be made from chrome-plated steel with diameters of 3 and 3.25 in, respectively. The total frame weight is 1050 lbm. The airlock for EGRESS cannot be mounted to the vehicle while the vehicle is in the shuttle bay; therefore, it too will be mounted within the shuttle bay in a separate framework assembly. Like EGRESS, the airlock will be mounted by means of a seven-point attachment scheme using longerons and keels.

Placement

Since the EGRESS vehicle will be docked on Space Station *Freedom*, the vehicle will impact the station and crew in many ways including docking/berthing, crew training, and station drills. The procedure for docking the EGRESS vehicle will be handled completely by remote manipulator arms of the Space Station. The vehicle will be extracted from the shuttle cargo bay by the Space Station's Remote Manipulator System (RMS), which will place the vehicle in its proper location on the station.

The first step in determining a location for the vehicles was the identification of ports on the Space Station that were already occupied. Ports 3 and 6 are reserved for space shuttle docking, and port 8 is an alternate location for *Freedom's* logistics module. Ports 1, 2, 4, and 5 were considered less desirable due to their proximity to the shuttle docking locations. Vehicles placed on these ports might interfere with the loading and unloading of payloads from the shuttle's cargo bay. In addition, vehicles placed at these locations would interfere with the field of vision from the cupolas, which will be the workstations from which *Freedom's* remote manipulator system will be operated. Thus ports 7 and 9, on nodes 1 and 2, were chosen for EGRESS placement. The vehicles are shown in their proper locations in Fig. 2.

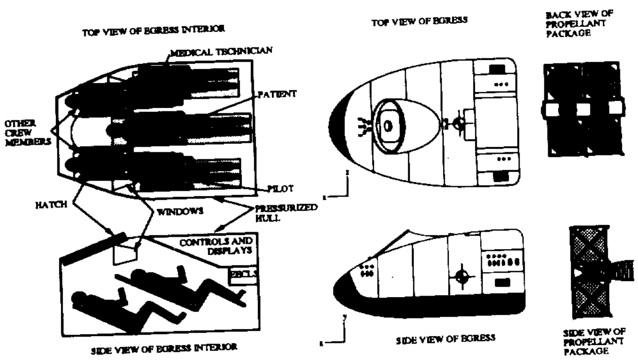

Fig. 2. Placement of EGRESS vehicles on Space Station *Freedom*

Maintenance

To minimize the effects of contaminants in the environment aboard the vehicle, as well as other primary sources of failure in equipment, the vehicle will be placed in a dormant state with its hatch closed while on-orbit. Remote-controlled diagnostic tests will be run periodically to detect any failure in the systems and results will be sent to ground control for analysis. Extensive maintenance check-ups will be performed semiannually for a complete inspection of all the components aboard EGRESS.

TRAINING

In order to minimize crew training aboard Space Station *Freedom,* all initial training will be performed on the ground with a proposed mock-up of an EGRESS to familiarize the pilot and crew with the vehicle systems and its internal configuration. Training will include piloting and navigation as well as use of all other systems onboard the EGRESS vehicle. Pilot training will also include familiarization with the back-up manual system. Basic repairs of the vehicle's main systems, maintenance, and checkout procedures will also be covered.

The space shuttle crew will undergo Apollo-type simulator training in addition to normal training in order to learn the EGRESS procedures. Each phase of Apollo training consisted of 1-hr oral briefings and 3-hr simulator exercises. The total training time was 200 hr of simulator exercises and 60 hr of briefings. The simulators were used for entry, rendezvous, and docking practice and were also used to simulate emergency situations. Thus, an EGRESS simulator environment must be designed and constructed for this training.

In order to properly utilize the EGRESS medical systems and supplies, the medical technician must be properly trained in both general medical procedures and in the use of the EGRESS equipment. Because present plans do not include a physician on Space Station *Freedom,* NASA will require the following medical training for the space station crewmembers: (1) All Space Station crewmembers shall be trained in basic first aid and Basic Life Support, including CPR; (2) Two crewmembers will have extensive medical training, such that one crewmember has specialized training equivalent to that of an emergency medical technician and an anesthetist/surgical assistant, and one crewmember has at least 100 hr of general medical training.

In the event that the EGRESS vehicle is used to transport an ill or injured crewmember to Earth, an EGRESS medical technician will be chosen from the two Space Station crewmembers who have had the most medical training and experience. Periodic on-orbit training will also be needed for the crew to maintain a basic knowledge of the operational procedures of the EGRESS vehicle. Subsequent pilot training will also be needed to insure proficiency in the manual backup system and maintain pilot familiarity with the cockpit. A simulator for piloting the vehicle should be provided aboard *Freedom.* Manuals and configuration drawings of the vehicle will also need to be available on the station for maintenance checkout and simple repairs.

CONCLUSION

Project EGRESS has designed a craft that meets the requirements of Johnson Space Center's Request for Proposal. The design was simple, reliable, and provided means for the evacuation of the Space Station or the return of an injured crewmember.

Three primary areas have been identified as needing further research. First, since the EGRESS will spend at least two years in the space environment, the effects of long-duration exposure on structural strength and life support systems must be determined. Second, procedures must be developed for retrieving the jettisonable propulsion pack after the deorbit burn. Third, the dynamic stability of the EGRESS within the supersonic flight regime must be addressed.

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